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A NEW METHOD FOR DETERMINING THE ABSORPTIVITY AND EMISSIVITY OF METAL WIRES

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ABSTRACT

Special problems in connection with the high solar intensities affecting space probe HELIOS caused investigations of the real energy consumption of thin wires and the arising temperatures.

As the values for absorptivity and emissivity mentioned in literature must be considered as uncertain, especially for temperatures up to 700 °C, a direct measurement procedure became necessary. At the same time also the individual qualities of the wires, as for instance the influence of the surface quality, could thus be determined.

INTRODUCTION

The antenna reflector of space probe HELIOS consists of a supporting structure and a wire grid. While the supporting structure is coated with second surface mirrors for controlling the temperature, the wire grid is made of thin metal wires without surface protection against high temperatures. Simple calculations indicate that depending on the type of metal, these wires can take 500 to 800 °C. Due to reflections from the structure elements, part of the wires can be radiated by double or triple irradiance. One must bear in mind that space probe HELIOS will be facing an irradiance of 16 solar constants in perihelion.

From this situation result considerable problems when choosing suitable wires for the antenna reflector. Of course a wire material had to be selected, the high temperature strength of which is sufficient to guarantee the mechanical structural stability of the antenna grid when the probe passes the sun.

There were not sufficient details for absorptivity and emissivity to be found in literature re the materials and temperatures involved; thus it became necessary to develop a measuring procedure for determining these values. The procedure had to refer to wire dimensions of the original size in order to be able to consider also the surface qualities of this wire. Besides the mechanical stability it is also important to have a rather low emissivity in order to keep the heat radiation from the antenna to the spacecraft as low as possible.

The test procedure described in the following is carried out in a smaller space chamber equipped with a solar simulator which generates 16 solar constants. Wires of various materials are irradiated, and the temperatures of these wires are measured by means of measurement of the electrical resistance of the wires. An exact determination of the temperature can be done from the known temperature coefficient. In a second consecutive procedure the wires are heated up to the same temperature without solar radiation by a current, the power of which is measured.

Description of the Experiments and Results

Wires of 0.2 mm diameter were used for the measurement. The measurement procedure is an absolute one. In order to obtain greater accuracy, various materials were simultaneously tested during each experiment so that the characteristics could be well compared. This is valid especially with respect to eventual deviations in the irradiance or in the spectral quality of the light.

Picture 1 shows a supporting frame to which the wires are fixed and where the electrical connectors are mounted. Each wire spans three times the length of 300 mm between the supporting fixtures. In this case, four wire materials are submitted to the test. The solar simulator irradiates the total area.

Behind the supporting frame a mirror is visible which was used for part of the tests, and which simulates reflections that are expected on the spacecraft under certain angles. Thus by this mirror a doubling of the intensity on the wires is practically produced by irradiating the wires also from behind.

The next picture shows a scheme of the chamber in order to demonstrate the location of the wires and the mirror inside the LN_2-cooled black wall. The resistance of the wires can be measured from outside by the normal method of resistance measurement with Wheatstone Bridge as well as by measuring current and voltage. The heat capacity of the wires is so small that the equilibrium is reached after a few minutes. This is the reason why the measurements at various irradiances can be carried out in a rather fast sequence.

Additionally it should be mentioned that the heat loss through the connections of the wire was considered as low. We realize that this means a certain inaccuracy, however, we consider that our assumption was permissible because of the small diameter of the wires of 0.2 mm on the one hand, and as we conducted comparison measurements of various materials which were subjected to the same condition on the other hand. It must also be pointed out that the heat loss occurred at the electrical connections only, and not at the other supporting points, which consist of small glass rods.

We conducted the measurements always twice, once with increasing and once with decreasing intensity. This enables us

1. to increase the measuring accuracy, and
2. to find out whether the characteristics of the wires have changed somewhat at the reached high temperature.

In some cases we found a certain change, especially in case the radiation took place for a prolonged period. We attributed this to the fact that the surface of the wire has changed by recrystallization, and thus the optical constants can also have been affected. The change of the surface was also proved in some cases by microphotographs of the wire (picture 3).

We have conducted two experiments. A scheme of experiments I and II is shown in picture 4. During the first experiment the wires were radiated and the temperatures were determined.

The optical constants α and ε and the arising temperature result from the equation

$$\alpha \cdot 1353 \cdot S \cdot \frac{A}{\pi} = \sigma \cdot \varepsilon \cdot T_1{}^4 \cdot A \qquad (1)$$

We thus obtain the ratio

$$\frac{\alpha}{\varepsilon} = \frac{\pi \cdot \sigma \cdot T_1{}^4}{1353 \cdot S} \qquad (1a)$$

α = absorptivity
S = number of solar constants
A = surface of the wire
σ = Stefan-Boltzmann constant
ε = emissivity
1 solar constant = 1353 Watts $\cdot$ m^{-2}

Immediately after the irradiation procedure the wires were heated by an external source of current. The current was so adjusted that the same resistance was obtained for each material as it was found during experiment I, corresponding to the various measured irradiances.

Experiment II is described by the equation

$$U \cdot I = \sigma \cdot \varepsilon \cdot T_1^4 \cdot A \tag{2}$$

This equation gives us the value of ε of the wire as a function of the temperature. It must be mentioned that this value does not only comprise the material characteristics, but also the surface condition of the wire. Therefore is is important to investigate that particular wire, which will be used later at the spacecraft, and not to investigate any other wire sample of that material.

By inserting equation 2 into equation 1, the absorptivity

$$\alpha = \frac{\pi \cdot U \cdot I}{1353 \cdot S \cdot A} \left[\frac{\text{Volt} \cdot \text{Amp.}}{\text{Watt} \cdot m^{-2} \cdot m^2}\right] \tag{3}$$

is obtained.

In our special example of application for project HELIOS we are interested to get a low value for the absorptivity, so that as little energy as possible is absorbed from the sun. At the perihelion of the HELIOS probe the total energy absorbed by the antenna grid amounts to approximately 30 Watts. It must be considered that an essential part of this energy is transferred by radiation into the central compartment through the louvers in the open position.

In picture 5 the measured values for the temperature are given for the metals gold, silver, and the alloy platinum 70/rhodium 30 with irradiances up to 16 solar constants. The resulting temperatures differ considerably. If reflections occur from the second surface mirrors of the spacecraft, as pointed out above, we have to expect about 800 °C for gold.

From the measurements it can be seen that silver has the most favorable values. Silver, however, cannot be used, as its high temperature strength is not sufficient. Therefore we have investigated a number of other materials, which for simplicity reasons are not contained in this graph. They are, however, mentioned in the following table (picture 6).

It points out the values of the absorptivity resulting from the calculation according to experiments 1 and 2. The absorptivity is mentioned for 100 °C, 300 °C, and 600 °C. At the first item there is no indication because the gold wire did not resist the full intensity, and it broke as it was too soft.

From the other materials we found that the alloys platinum/rhodium and platinum/iridium are most favorable, especially iridium. Thus we have recommended to use platinum/iridium. These materials have an ample high temperature strength.

Some peculiarities of the values may be caused by the surface condition of the wire. This is true especially for rhodium. That wire had an unfavorable surface which could be noticed at first sight. The rhodium wire was very interesting during the experiment because it taught us to recognize that a material for which the optical characteristics are very favorable in literature, was the worst case in the form of a wire. The reason is the manufacturing difficulty of this wire, due to its brittleness.

It is now important to say some words about the defining of temperature with the aid of the resistance. Because of the strong functional dependence between the contamination in the metals and the resistance, as well as of the temperature coefficient of the resistance, it is not possible to use the values mentioned in literature. These data are available for pure metals and for limited temperatures only.

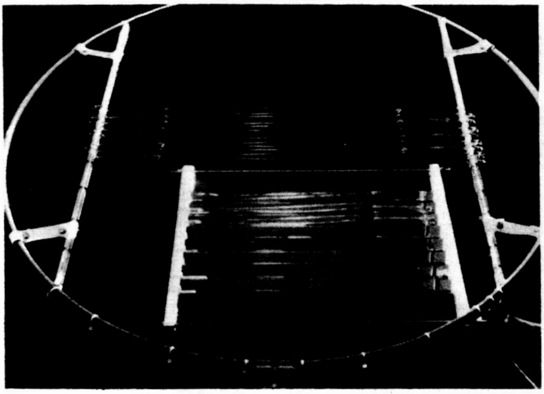
Therefore, in a simple apparatus, we have determined separately the resistance of the wire for the temperature concerned. To achieve this, the wire was heated in an evacuated tube furnace. The scheme of this apparatus is shown in picture 7 and should be understandable without further explanations. From the measured resistance values we have determined the coefficients A and B for the resistance equation

$$R_t = R_o \cdot (1 + A \cdot t + B \cdot t^2) \qquad (4)$$

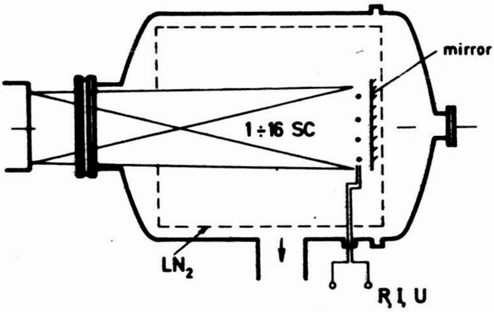
$$t = T - 273$$

We have used these coefficients to determine the temperatures pointed out above.

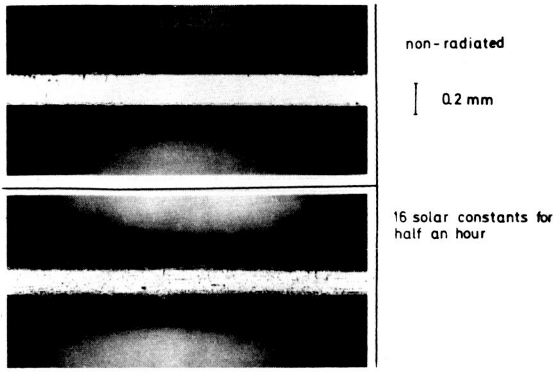
It seems to us that the mentioned method for determining the optical constants of wires can be easily performed in practice. In our case it was especially suitable in order to comprise the influence of the wire's surface. As the results have shown, it is important to consider the surface quality. The manufacturer of the wires should especially take care of the surface quality, that means he has to use very good drawing dies.



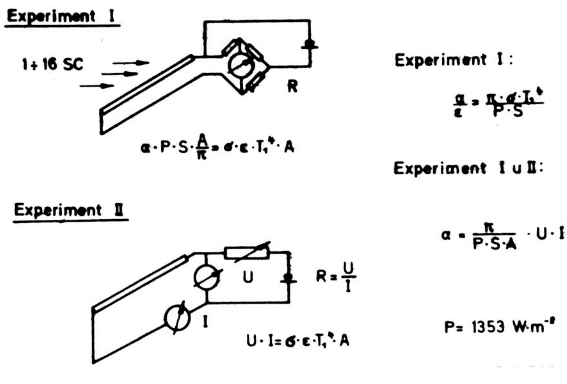
Picture 1: Supporting frame with 4 wire materials and mirror behind them



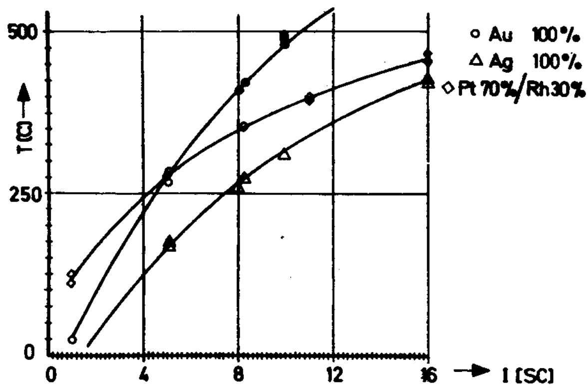
Picture 2: α & ε measurements on wires in a space chamber



Picture 3: Microphotographs of the Ag-wire



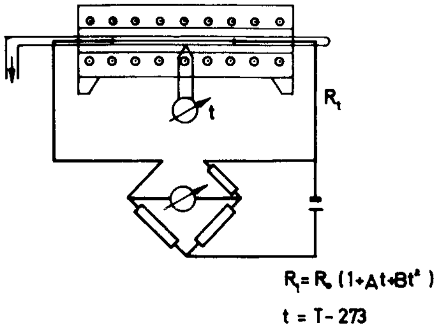
Picture 4: Scheme of the α & ε measurements



Picture 5: Wire temperatures in dependence of solar irradiance

Material	α (100°C)	α (300°C)	α (600°C)
Au	-	-	-
Ag	0,19	0,09	0,14
Au 50/Ag 50	0,21	0,17	0,19
Pt	0,37	0,35	0,29
Pt 90 / Ir 10	0,39	0,39	0,38
Pt 80 / Ir 20	0,16	0,13	0,13
Pt 70 / Ir 30	0,16	0,06	-
Rh	0,61	0,46	0,53
Pt 80 / Rh 20	0,26	0,31	0,29
Pt80 / Rh 20+Ag	0,11	0,10	0,11
Pt 70 / Rh 30	0,29	0,29	0,29

Picture 6: Absorptivity resulting from Experiment I and Experiment II



Picture 7: Determination of the temperature coefficient of the wire resistance